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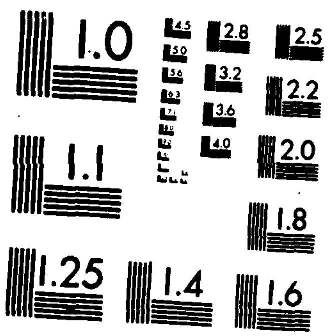


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# PHYSIOLOGICAL ASSESSMENTS OF CHEMICAL THREAT PROTECTIVE PATIENT WRAPS IN THREE ENVIRONMENTS

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Comparisons of physiological responses of eight resting supine subjects to 2-h encapsulation in the current chemical warfare agent protective patient wrap, and seven prototypes were conducted in a warm ($T_{db}$=30°C, $T_{dp}$=7°C) environment. Oxygen ($O_2$) and carbon dioxide ($CO_2$) concentrations within the wrap, and the subjects' rectal temperature ($T_{re}$), heart rate (HR) and sweating rates were determined. The subjects' sweating rates and final $T_{re}$ and HR were not different among wraps. Two prototype wraps were further tested in the heat ($T_{db}$=49°C, $T_{dp}$=17°C) and cold ($T_{db}$=-39°C). The chosen wraps were the wrap of Nyco twill shell and 3M melt-blown polypropylene core which showed the smallest changes in $O_2$ and $CO_2$ (final $O_2$ = 19.3%, $CO_2$ = 1.2%) of the prototypes, and the Nyco oxford shell and Bondina Mark IV core wrap which had the third smallest changes in $O_2$ and $CO_2$ levels (final $O_2$ = 18.8%, $CO_2$ = 1.6%) in the warm environment. Both wraps resulted in the smallest $T_{re}$ increase (0.2°C) in the warm environment. In the heat, final $O_2$ concentration was greater (0.5%; $p < 0.05$) and final $CO_2$ concentration was less (0.5%; p = 0.05) for the Nyco twill 3M wrap although final $T_{re}$, HR and

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weight loss were not different between wraps. In the cold, there were no differences between the wraps in these physiological responses. These results show that the Nyco twill 3M patient wrap is equal or better than the six prototype wraps in the warm and hot environments, and performs as well as the Bondina Mark IV in the cold.

# ABSTRACT

Comparisons of physiological responses of eight resting supine subjects to 2-h encapsulation in the current chemical warfare agent protective patient wrap, and seven prototypes were conducted in a warm ($T_{db}$=30°C, $T_{dp}$ = 7°C) environment. Oxygen ($O_2$) and carbon dioxide ($CO_2$) concentrations within the wrap, and the subjects' rectal temperature ($T_{re}$), heart rate (HR) and sweating rates were determined. The subjects' sweating rates and final $T_{re}$ and HR were not different among wraps. Two prototype wraps were further tested in the heat ($T_{db}$ = 49°C, $T_{dp}$ = 17°C) and cold ($T_{db}$= -39C). The chosen wraps were the wrap of Nyco twill shell and 3M melt-blown polypropylene core which showed the smallest changes in $O_2$ and $CO_2$ (final $O_2$ = 19.3%, $CO_2$ = 1.2%) of the prototypes, and the Nyco oxford shell and Bondina Mark IV core wrap which had the third smallest changes in $O_2$ and $CO_2$ levels (final $O_2$ = 18.8%, $CO_2$ = 1.6%) in the warm environment. Both wraps resulted in the smallest $T_{re}$ increase (0.2°C) in the warm environment. In the heat, final $O_2$ concentration was greater (0.5%; $p < 0.05$) and final $CO_2$ concentration was less (0.5%; $p$ = 0.05) for the Nyco twill 3M wrap although final $T_{re}$, HR and weight loss were not different between wraps. In the cold, there were no differences between the wraps in these physiological responses. These results show that the Nyco twill 3M patient wrap is equal or better than the six prototype wraps in the warm and hot environments, and performs as well as the Bondina Mark IV in the cold.

## INTRODUCTION

Combat on a chemically contaminated battlefield exists as a possibility for the foreseeable future. Among the problems this presents for the military medical community is transport of injured troops either from or through an area contaminated by chemical agents. The British chemical protective casualty wrap which is currently used in Europe is one means of protecting injured soldiers.

It was determined by the U.S. Army Office of the Surgeon General that an improved protective patient wrap should be developed which should be composed of a water repellent material including improved access to the patient, and providing a minimum of six hours protection to unmasked uncontaminated patients in wind speeds up to 20 knots. Six such prototype wraps were developed under the guidance of the U.S. Army Medical Bioengineering Research and Development Laboratory. These wraps were then submitted for testing as to effectiveness in protecting against chemical threat agents and also ability to provide needed gas exchange to humans for extended periods.

We studied the effect of the wraps on encapsulated subjects by measuring the oxygen depletion and carbon dioxide accumulation within the wrap and the core temperature and heart rate of the subjects in a warm environment. The six prototype wraps were additionally compared to the United Kingdom wrap and an improved United Kingdom wrap. Two prototype wraps were then chosen for testing in two extreme environments and a second series of experiments were undertaken to provide preliminary data on safe exposure time during encapsulation in extreme hot and cold environments.

## MATERIALS AND METHODS

Eight chemical warfare agent protective patient wraps were tested after approval of the experimental protocol by the local and U.S. Army Medical Research and Development Command committees for human research: six experimental wraps, the standard U.K wrap and a new U.K. wrap. The experimental wraps were composed of an impermeable ground sheet and an upper blanket of chemical protective, laminated cloth. There was a clear window in the upper blanket where the solider's head was positioned. Each experimental prototype utilized the same materials for the window and ground sheet. The window was a tri-laminated nylon/saran/polyethylene film. The ground sheet was Loretex and nylon. The shell and carbon based core materials of each experimental prototype varied (Table 1).

Eight men volunteered to be subjects after being fully briefed and having read an informed consent form. The subjects had a mean (±S.D.) height of 174.3 (±4.4) cm, Dubois surface area of 1.89 (±0.13) $m^2$, age of 22.8 (±3.4) yrs and resting metabolic rate of 0.32 (±0.03) $l\ O_2 \cdot min^{-1}$. Resting metabolic rates were measured by open circuit spirometry using an MMC Horizon System (Sensormedics) (1) while subjects were supine and in a fasted state. Prior to the first experiment, each subject was familiarized with the patient wrap and the experimental protocol.

The experimental protocol for comparing physiologic responses to encapsulation in the eight wraps was the same for each experiment. The experiments were conducted in an environmental chamber with a dry bulb temperature ($T_{db}$) of 29.90 (±0.46)°C and a dew-point temperature ($T_{dp}$) of 6.89 (± 2.14)°C. The subject was initially weighed nude. He inserted a YSI rectal thermistor 10 cm past the anal sphincter for the measurement of rectal temperature ($T_{re}$). ECG electrodes and leads were attached for heart rate (HR)

measurement. The subject then dressed in temperate battle dress uniform and boots. A small diameter polyethylene tube, which was attached to a pump so that a continuous air sample could be drawn from within the wrap, was then positioned at the bridge of the nose. The $O_2$ concentration of this sample of air was analyzed by an Applied Electrochemistry S-3A Analyzer. The $CO_2$ concentration was measured by a Beckman LB-2 $CO_2$ Analyzer. The subject lay quietly for at least 30 min on the bottom layer of the patient wrap, ensuring that $T_{re}$ was stable before the experiment began. The subject was then encapsulated in the wrap. $O_2$ concentration, $CO_2$ concentration, and $T_{re}$ were measured every minute. Heart rate was measured every 5 minutes. Subjects were encapsulated in the wrap for two hours if $O_2$ concentration did not fall below 16%. In some cases, $O_2$ concentration fell below 16%, and the experiment was terminated. After the two hours of encapsulation, an impermeable film was fastened over the experimental patient wrap. This film is to increase protection at high wind speeds for short periods of time. $O_2$ and $CO_2$ concentration, and $T_{re}$ were monitored every 30 sec and HR was measured every min after the film was attached. The film was removed when the $O_2$ concentration fell to 16% (range = 1.5-21.1 min). The subject remained in the wrap for 20 min after the film was removed. Subjects were weighed after the experiment.

Two wraps were chosen for further testing in two extreme environmental conditions. Six men were studied during two hours of encapsulation (no film attached) in hot-dry, (49.1(±0.43)°C, $T_{db}$; 17.0 (±0.26)°C, $T_{dp}$) and in cold-dry ($T_{db}$ = -38.83 (± 0.74) °C) environments. Subject's wore the hot weather battle dress uniform in the hot-dry environment and the standard cold-dry uniform (clo=4.30(3)) during the cold exposure. The mean (±S.D.) age, height, weight, DuBois body surface area ($A_D$) and resting metabolic rate of the subjects were 25.8 ± 5.7 yrs, 174.9 ± 4.8 cm, 74.9 ± 9.5 kg, 1.90 ± 0.11 $m^2$ and 0.27 ± 0.03

$l\ O_2 \cdot min^{-1}$, respectively.

The $T_{re}$ and the index finger temperature ($T_{finger}$) were measured continuously during the cold-dry experiments. The experiment was terminated if $T_{finger}$ fell below 10°C or if the subject felt too cold to remain encapsulated. Air samples were not collected during this phase of the study.

A counterbalanced repeated measures experimental design was employed to control for familiarity to encapsulation. A one-way analysis of variance with repeated measures was used to determine differences between the wraps for change in $T_{re}$, sweating rate, final $O_2$ and $CO_2$ concentrations and predicted $T_{re}$, $T_{finger}$ and weight loss after 3 or 6 h of encapsulation. These predicted values were determined by calculating the change in parameter per minute during actual data collection, then multiplying the rate of change by the number of minutes for which the prediction was desired. A two-way analysis of variance with repeated measures (wrap x time) was used to reject the null hypothesis for $O_2$ and $CO_2$ accumulation, $T_{re}$, and heart rate. Tukey's test of critical differences was used where appropriate (2). All critical differences reported are at $p < 0.05$.

## RESULTS

During the 30°C tests comparing all eight wraps, the subjects generally remained encapsulated for 2 hours. However, in some instances the experiments were terminated before 2 hours because $O_2$ concentration decreased below 16%. All subjects were encapsulated for at least 48 min in all wraps, therefore time analyses of the data were done for that duration.

Oxygen and carbon dioxide concentrations within the wraps were generally stabilized during the first 25 min of encapsulation (Figure 1). When $O_2$ concentration was analyzed by 2-way analysis of variance with repeated

measures including all subjects during the first 48 minutes of encapsulation (subject 2 was removed from Wrap 5 at this time), there was greater oxygen depletion in Wrap 7 ($F=6.81$; $df=7,49$; $p < 0.05$) than Wraps 1,3 and 8. There was also greater $O_2$ depletion in Wraps 2,4 and 6 than Wrap 1. Wrap 5 was not different than any other wrap. While Wrap 7 had the largest oxygen depletion, the mean $O_2$ concentration remained greater than 18% during the first 48 minutes of encapsulation. However, in three cases the experiment had to be stopped after that time due to $O_2$ concentrations less than 16% during encapsulation in Wrap 7. During the initial 48 minutes, $CO_2$ concentration was significantly higher ($F=6.94$; $df=7,49$; $p < 0.05$) in Wrap 7 than in Wraps 1,3 and 8 and also higher in Wraps 2,4, and 6 than in Wrap 1. However, the $CO_2$ concentration within Wrap 7 remained less than 3% during the first 48 min of encapsulation (Figure 1). Again Wrap 5 was not different than any other wrap.

The analyses of the initial 48 minutes of encapsulation indicates that all wraps met the initial specifications for $O_2$ depletion and $CO_2$ accumulation ($O_2$ concentration, $\geq$ 18%; $CO_2$ concentration, $\leq$ 3%). However, $O_2$ concentration decreased over the entire 2 hours of encapsulation prior to putting on the impermeable film. While the experiment was terminated before 2 hours of encapsulation on five instances, a comparison of the final $O_2$ and $CO_2$ concentrations in the wraps was made. Therefore, in those instances when the experiment was terminated, the last $O_2$ or $CO_2$ concentration measured was used as the final value. Using this criterion, the final $O_2$ concentration was not different among Wraps 1,3,4,5,6, and 8 but $O_2$ concentration was, significantly ($F=5.52$; $df = 7,49$; $p < 0.05$) lower in Wrap 7 than in Wraps 1,3 and 8 and in Wrap 2 than Wraps 1 and 3. (Figure 2). Similarly, Wraps 1,3 and 8 had significantly lower ($F=5.60$, $df=7,49$; $p < 0.05$) $CO_2$ concentrations than Wrap 7 while Wraps 1 and 3 were less than Wrap 2. (Figure 3). Also, the final mean $O_2$ concentration in Wrap 7 was less than 18% (17.62%).

Rectal temperature ($T_{re}$) increased as a function of time in all wraps, but no significant differences were shown among the 8 wraps in the 30°C experiments. Wrap 1 did appear to be the most conducive to heat dissipation (Table 2), but it did not have an outer shell as did all the other wraps. The $T_{re}$ increased by 0.2°C during encapsulation in Wraps 3 and 5, which was the smallest increase in the prototype wraps. Additionally, the sweating rate was not different among the patient wraps in the 30°C experiments (Table 3). Predicted weight loss from sweating after six hours of encapsulation was not different among the wraps, and encapsulation for that length of time would result in dehydration of up to 1.5% of body weight.

The heart rate (HR) was not different among the prototype patient wraps (Table 2). However, the average HR of 84 (±10) $b \cdot min^{-1}$ in Wrap 5 was statistically greater ($F=2.46$; $df=7,49$; $p < 0.05$) than the average 71 (± 10) $b \cdot min^{-1}$ in Wrap 1.

Further testing was conducted on two experimental wraps in more extreme hot and cold environments. Wraps 3 and 5 were chosen for these experiments because, while not statistically significant, encapsulation in those wraps at 30°C resulted in lower $T_{re}$ increases than the other experimental prototypes.

The experiments at environmental extremes indicated that there were slight differences between Wraps 3 and 5. In the hot environment, one subject's rectal temperature increased to 39.2°C in both wraps and consequently, he was removed. The mean (± S.D.) time of encapsulation in Wrap 3 was 92.3 (± 26.5) min and 94.6 (± 27.9)min in Wrap 5, which was not statistically different. The final $O_2$ concentration during encapsulation was greater in Wrap 3 ($F=13.98$, $df=5$, $p < 0.05$). The concentration of $O_2$ in Wrap 5 did not fall below 18.57% and was only 0.4% lower than in Wrap 3 (18.99%). Although the final $CO_2$ concentration was not statistically different between wraps, there was a very

strong trend toward differences ($p = 0.05$), with the $CO_2$ concentration in Wrap 3 (0.90%) being less than Wrap 5 (1.30%). Final $T_{re}$ was not different between wraps. The predicted increase in $T_{re}$ for 3 h of encapsulation in Wrap 3 was 2.2 ($\pm$ 0.6)°C and 2.1 ($\pm$0.6)°C for Wrap 5, and was also not different between wraps. There was no difference in weight loss between the wraps. The average weight loss was 1.2 ($\pm$0.7) kg in Wrap 3 and 1.3 ($\pm$0.3) kg in Wrap 5. The predicted weight loss after 3 h was 2.2 ($\pm$0.9) kg in Wrap 3 and 2.5 ($\pm$0.6) kg in Wrap 5. There was no difference in heart rate between the wraps.

In the -40°C environment there were no significant differences between wraps. The time of encapsulation averaged 76.5 ($\pm$10.6) min in Wrap 3 and 68.6 ($\pm$10.3) min in Wrap 5. $T_{re}$ decreased 0.65 ($\pm$0.4)°C in Wrap 3 and 0.46 ($\pm$0.2)°C in Wrap 5. $T_{finger}$ decreased from 30.8 ($\pm$ 5.2)°C to 14.4 ($\pm$ 5.0)°C in Wrap 3 and from 29.0 ($\pm$ 4.2) °C to 14.8 ($\pm$5.2)°C in Wrap 5. Weight loss was negligible in both wraps, and heart rate was not different between wraps. Predicted $T_{re}$ at 3 h were not significantly different. $T_{re}$ was predicted to decrease 1.49 ($\pm$ 0.7)°C in Wrap 3 and 1.27 ($\pm$ 0.6)°C in Wrap 5. Predicted $T_{finger}$ after 3 h were not different between wraps. In both, the fingers would suffer cold injury as the finger temperature could approach O°C. These predictions are for nonstressed subjects dressed in the full Arctic ensemble, which included 3 layers of insulation (clo = 2.18 (3)) for the hands.

## DISCUSSION

With the exception of Wrap 7, all of the prototypes met the requirements as set by the US Army Office of the Surgeon General because $O_2$ concentration was greater than 18% and $CO_2$ concentration less than 3% when subjects were encapsulated for 2 hours at 30°C $T_{db}$, 7°C $T_{dp}$. However, while the $O_2$ depletion and $CO_2$ accumulation data from this study indicate safe transport for

soldiers for up to 6 hours certain other questions are raised by the results of the experiments.

When comparing Wraps 3 and 5, which were used in all three environments, the differences between them were minor but of possible importance. While not statistically significant, Wrap 3 did have higher mean $O_2$ concentration and lower mean $CO_2$ concentration than Wrap 5 in the 30°C environment. In the 49°C environment there was a significant difference in $O_2$ level between the two wraps. This 0.4% difference would make little difference at sea level. However, the lower partial pressures of $O_2$ that occur at high altitude, such as on mountain ranges, could result in a physiological difference for subjects in these two different wraps.

The area of greater concern with the prototype patient wraps relates to the consequences of the patients exposure to environmental extremes. In the 49°C environment, our subjects lasted an average of 92.3 and 94.6 minutes in Wraps 3 and 5, respectively. These times were achieved with healthy, fully hydrated subjects. It should be noted that at the termination of the 49°C tests the mean core temperatures of the subjects were 38.2 and 38.0°C and heart rates were 107 and 106 $b \cdot min^{-1}$ in Wraps 3 and 5, respectively. Therefore, while the subjects were subjectively uncomfortable, most were not in immediate thermoregulatory jeopardy. Dehydration or hypovolemia from any means would result in decreased sweating rate and therefore decreased evaporation which would increase $T_{re}$ (4,5). Any changes in ambient conditions such as addition of solar radiation, increased ambient temperature, or increased relative humidity would increase the thermal stress on the patients and shorten the predicted times of safe encapsulation.

Atropine is currently the treatment drug of choice in cases of organophosphate poisoning. It can therefore be postulated that some patients in

the protective wraps will have received atropine treatment. In previous laboratory experiments, subjects injected with 2 mg of atropine i.m. (equivalent to one auto-injector) have had consistently decreased sweating rates of approximately 45% during exercise in various environments (6,7,8). A sweating decrease of this magnitude would be highly detrimental to patients encased in the wraps as $T_{re}$ would increase more rapidly than indicated by our prediction. In addition, it is likely that in a battlefield situation a casualty would receive more than one auto-injector of atropine which could potentially result in an even greater increase in core temperature lessening the safe encapsulation time (9).

Testing in the -40°C environment also indicated severe problems for casualties with prolonged encapsulation. Our subjects were dressed in the standard cold-dry uniform, including three layers on the hands providing insulation of 2.18 clo. Even with this protection, three hour predicted $T_{finger}$ values show decreases of 39°C and 40°C for wraps 3 and 5 respectively, which would result in tissue damage to the hands. The predicted three hour drop in core temperature shows that casualties would still be above 35.5°C in both wraps which would pose no immediate threat to life, but perhaps hands and feet, and at least fingers and toes could be frozen. It should be mentioned again, that these results are from healthy, well-rested individuals under no stress other than the cold. Further caution is required in this cold environment because the casualties could have the injured area exposed for treatment which would drastically reduce insulation and increase heat loss.

In conclusion, the newly designed patient wraps afford good $O_2$ and $CO_2$ exchange, relative to the current British wrap. However, this study indicates that while gas exchange does not appear to be a limiting factor, temperature regulation will be a problem in extreme hot and cold environments if the wraps are used for six hours as currently specified. Furthermore, problems are

indicated at moderate temperatures, if casualties receive drug therapy, such as atropine, and their thermoregulatory responses will require close observation.

## ACKNOWLEDGMENTS

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The opinions and/or findings presented in this paper are those of the authors and should not be construed as official Department of the Army position, policy or decision. Human subjects participated in these experiments after giving their free and informal consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on the Use of Volunteers in Research.

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Table 1. Description of chemical warfare agent protective patient wraps.

| | SHELL | CORE (CARBON BASED) |
|---|---|---|
| 1. | NONE (Standard United Kingdom) | Bondina Mark IV |
| 2. | Fire resistant cotton/Tyvek (New United Kingdom) | Modified Mark IV |
| 3. | Nyco Twill | 3M Melt Blown Polypropylene |
| 4. | Von Blucher "Hylla" | Von Blucher Saratoga |
| 5. | Nyco Oxford | Bondina Mark IV |
| 6. | Nyco Twill | 50 ml Polyurethane Foam |
| 7. | Nyco Twill | Von Blucher Saratoga |
| 8. | Nyco Oxford | Lantor Mark IV |

Table 2. Mean (± SD) increase in core temperature ($\Delta T_{re}$) during encapsulation, the $\Delta T_{re}$ predicted after 6 hours of encapsulation, and final heart rate (HR) during encapsulation at $T_{db}$ = 30°C, $T_{dp}$ = 7C.

| | Wrap 1 | Wrap 2 | Wrap 3 | Wrap 4 | Wrap 5 | Wrap 6 | Wrap 7 | Wrap 8 |
|---|---|---|---|---|---|---|---|---|
| $\Delta T_{re}$ (°C) | 0.07 (0.05) | 0.21 (0.06) | 0.21 (0.16) | 0.30 (0.14) | 0.21 (0.11) | 0.25 (0.09) | 0.22 (0.12) | 0.25 (0.12) |
| Predicted $\Delta T_{re}$ after 6h | 0.17 (0.10) | 0.60 (0.31) | 0.49 (0.34) | 0.74 (0.29) | 0.50 (0.23) | 0.60 (0.20) | 0.56 (0.29) | 0.59 (0.27) |
| HR ($b \cdot min^{-1}$) | 71 (10.2) | 81 (4.1) | 79 (6.7) | 82 (8.8) | 84 (10.1) | 80 (10.5) | 78 (13.8) | 73 (6.8) |

Table 3. Mean (± S.D.) sweating rate during encapsulation and the predicted weight loss, based on this sweating rate, after 6 hours of encapsulation at $T_{db}$=30°C, $T_{dp}$= 7°C.

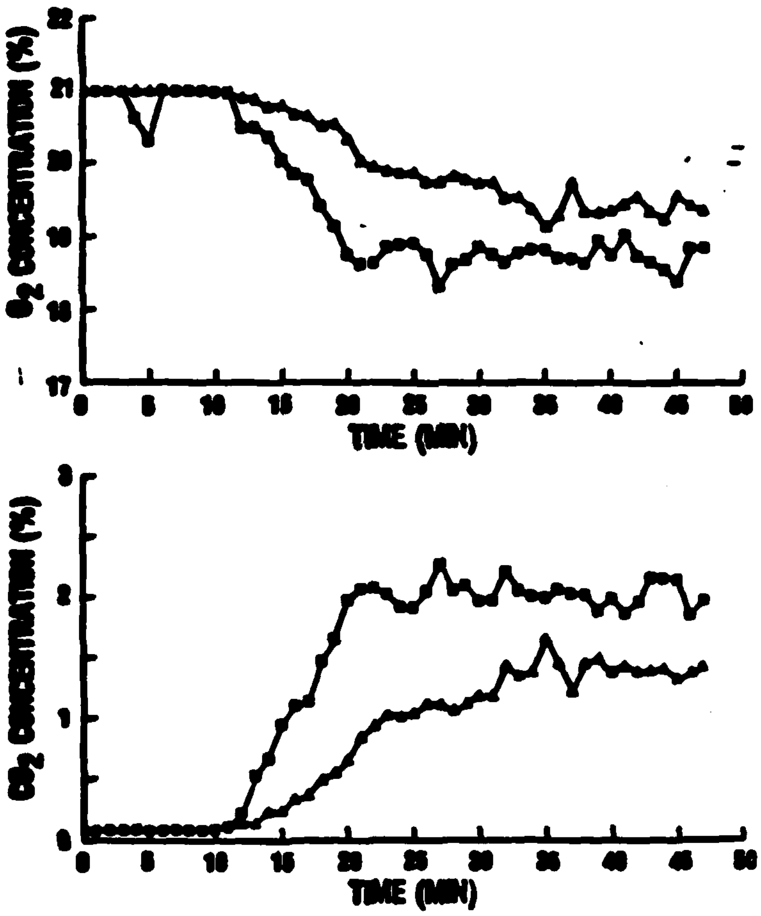
| | Wrap 1 | Wrap 2 | Wrap 3 | Wrap 4 | Wrap 5 | Wrap 6 | Wrap 7 | Wrap 8 |
|---|---|---|---|---|---|---|---|---|
| Sweating Rate ($g \cdot min^{-1}$) | 2.20 (1.37) | 2.11 (0.86) | 3.03 (1.2) | 2.36 (1.57) | 2.56 (1.33) | 2.00 (1.06) | 2.60 (1.31) | 2.69 (1.24) |
| Predicted Weight Loss after 6 h (kg) | 0.79 (0.49) | 0.77 (0.31) | 1.09 (0.43) | 0.85 (0.56) | 0.92 (0.48) | 0.72 (0.38) | 0.94 (0.48) | 0.97 (0.45) |

## Figure Legends

Figure 1. Mean $O_2$ concentration (top) and $CO_2$ concentration (bottom) during the first 48 minutes of encapsulation in the wraps which exhibited the greatest (Wrap 3; Δ) and least (Wrap 7■) gas exchange in the $T_{db}$=30°C, $T_{dp}$=7°C experiments.

Figure 2. Final mean oxygen concentrations at $T_{dp}$=30°C, $T_{dp}$=7°C.
* Wrap 7 significantly less than Wraps 1,3 and 8 ($p < 0.05$).
+ Wrap 2 significantly less than Wraps 1 and 3 ($p < 0.05$).

Figure 3. Final mean carbon dioxide concentrations at $T_{dp}$=30°C, $T_{dp}$=7°C
* Wrap 7 greater than Wraps 1,3 and 8 ($p < 0.05$).
+ Wrap 2 greater than Wraps 1 and 3 ($p < 0.05$).



$O_2$ CONCENTRATION (%)
22
21
20
19
18
17
0
5
10
15
20
25
30
35
40
45
50
TIME (MIN)
$CO_2$ CONCENTRATION (%)
3
2
1
0
0
5
10
15
20
25
30
35
40
45
50
TIME (MIN)


Figure 1

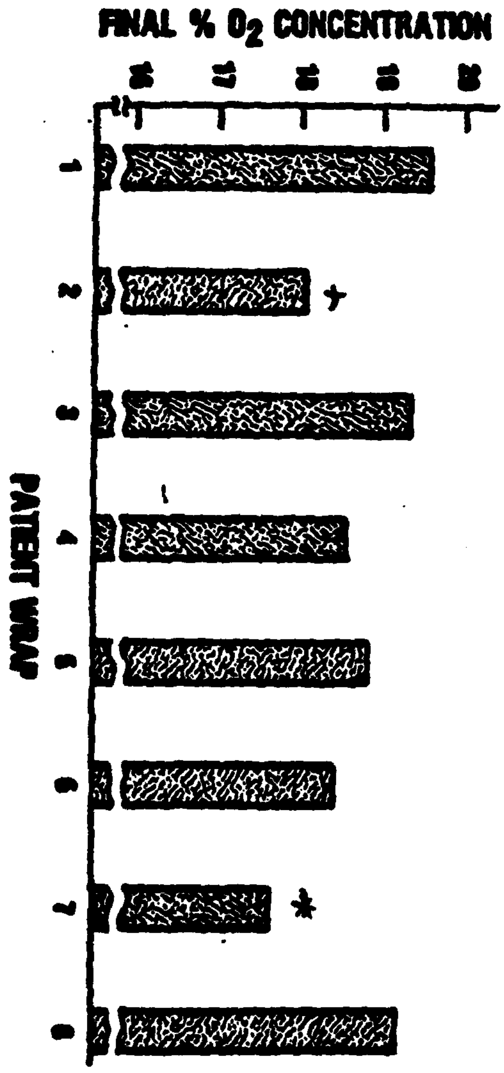



Figure 2

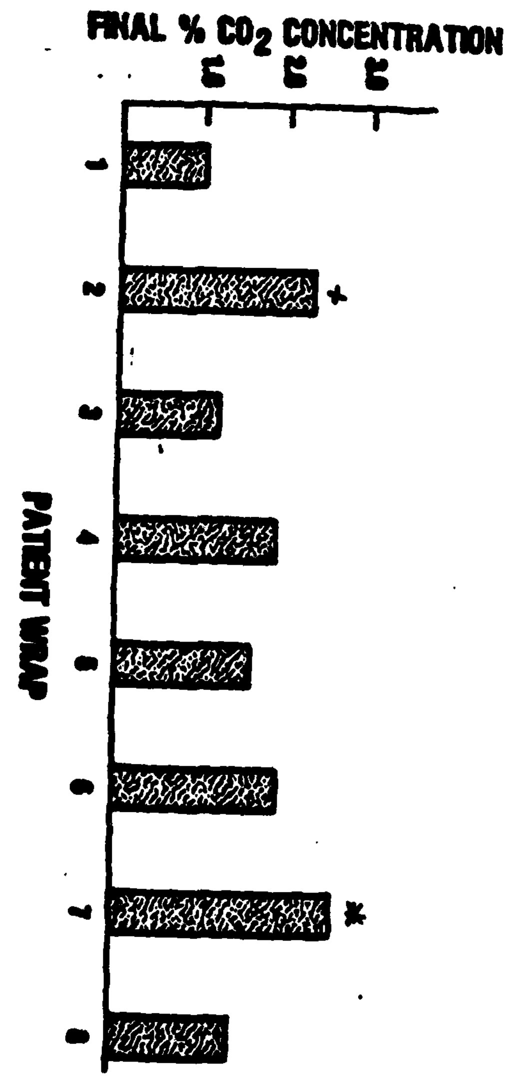



Figure 7

END

12-86

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